

FIG. 1

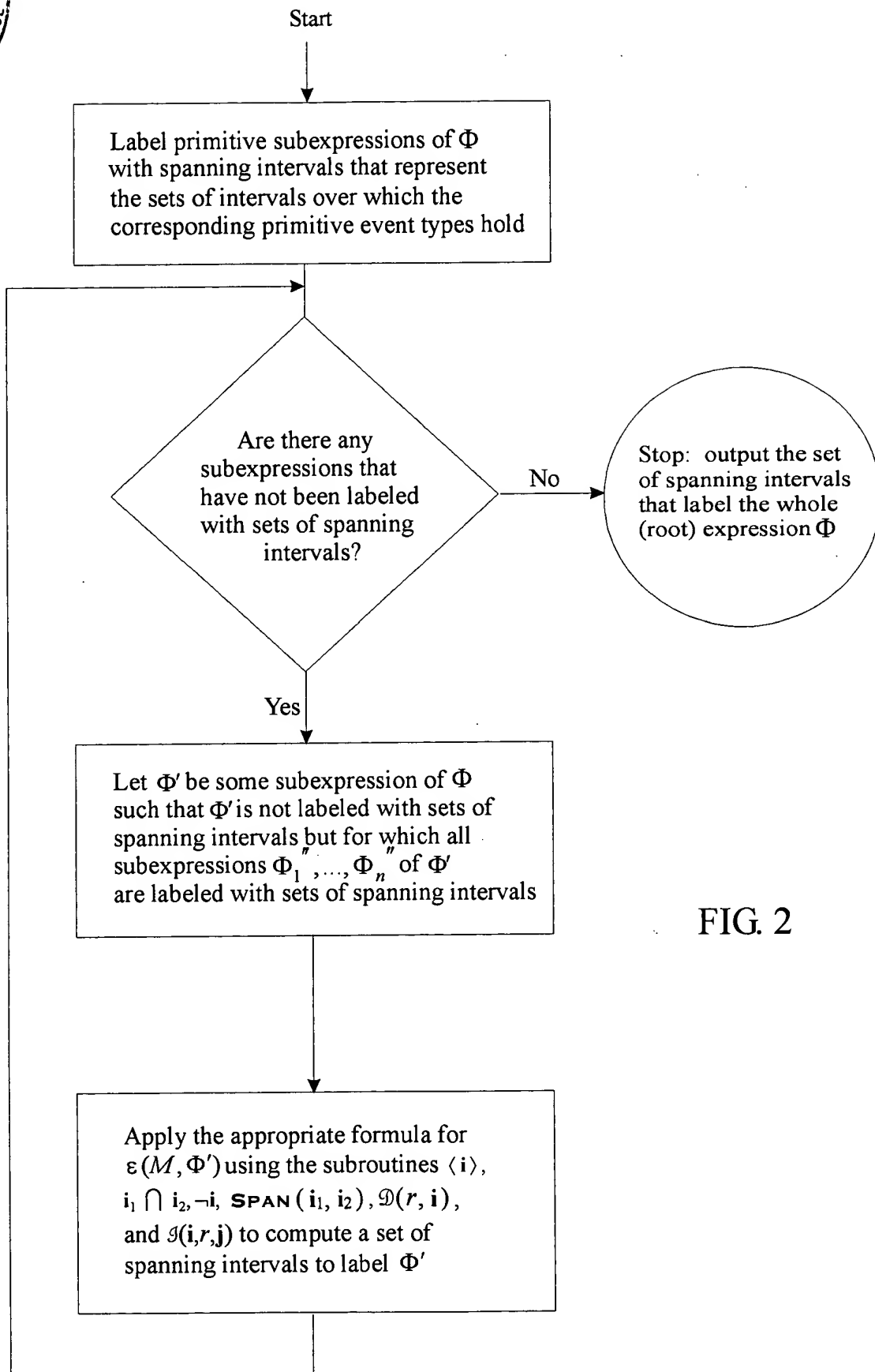


FIG. 2



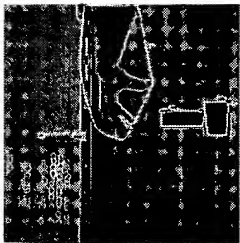
$$\begin{aligned}
 x = y &\triangleq \overline{x = y} \\
 \text{SUPPORTED}(x) &\triangleq \overline{\neg \text{GROUNDED}(x)} \\
 \text{RIGIDLY ATTACHED}(x, y) &\triangleq (\exists r) \text{RIGID}(x, y, r) \\
 \text{SUPPORTS}(x, y) &\triangleq \overline{\left(\begin{array}{l} \neg \text{GROUNDED}(y) \wedge \\ \neg \text{STABLE}(P \setminus \{x\}, M \cup \{\text{GROUNDED}(z) | \neg \text{RIGIDLY ATTACHED}^*(z, y)\}) \end{array} \right)} \\
 \text{CONTACTS}(x, y) &\triangleq \overline{\text{TOUCHES}(x, y) \wedge x \bowtie y} \\
 \text{ATTACHED}(x, y) &\triangleq \overline{(\exists r) \text{RIGID}(x, y, r) \vee \text{REVOLUTE}(x, y, r)}
 \end{aligned}$$

FIG. 3

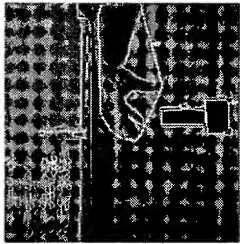


$$\begin{aligned}
\text{PICKUP}(x, y, z) &\triangleq \left(\begin{array}{l} \neg \Diamond x = y \wedge \neg \Diamond z = x \wedge \neg \Diamond z = y \wedge \\ \text{SUPPORTED}(y) \wedge \neg \Diamond \text{ATTACHED}(x, z) \wedge \\ \left[\begin{array}{l} \neg \Diamond \text{ATTACHED}(x, y) \wedge \neg \Diamond \text{SUPPORTS}(x, y) \wedge \\ \text{SUPPORTS}(z, y) \wedge \\ \neg \Diamond \text{SUPPORTED}(x) \wedge \neg \Diamond \text{ATTACHED}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(y, x) \wedge \neg \Diamond \text{SUPPORTS}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(x, z) \wedge \neg \Diamond \text{SUPPORTS}(z, x) \end{array} \right] ; \\ \left[\begin{array}{l} \text{ATTACHED}(x, y) \vee \text{ATTACHED}(y, z) ; \\ \text{ATTACHED}(x, y) \wedge \text{SUPPORTS}(x, y) \wedge \\ \neg \Diamond \text{SUPPORTS}(z, y) \wedge \\ \neg \Diamond \text{SUPPORTED}(x) \wedge \neg \Diamond \text{ATTACHED}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(y, x) \wedge \neg \Diamond \text{SUPPORTS}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(x, z) \wedge \neg \Diamond \text{SUPPORTS}(z, x) \end{array} \right] \end{array} \right) \\
\\
\text{PUTDOWN}(x, y, z) &\triangleq \left(\begin{array}{l} \neg \Diamond x = y \wedge \neg \Diamond z = x \wedge \neg \Diamond z = y \wedge \\ \text{SUPPORTED}(y) \wedge \neg \Diamond \text{ATTACHED}(x, z) \wedge \\ \left[\begin{array}{l} \text{ATTACHED}(x, y) \wedge \text{SUPPORTS}(x, y) \wedge \\ \neg \Diamond \text{SUPPORTS}(z, y) \wedge \\ \neg \Diamond \text{SUPPORTED}(x) \wedge \neg \Diamond \text{ATTACHED}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(y, x) \wedge \neg \Diamond \text{SUPPORTS}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(x, z) \wedge \neg \Diamond \text{SUPPORTS}(z, x) \end{array} \right] ; \\ \left[\begin{array}{l} \text{ATTACHED}(x, y) \vee \text{ATTACHED}(y, z) ; \\ \neg \Diamond \text{ATTACHED}(x, y) \wedge \neg \Diamond \text{SUPPORTS}(x, y) \wedge \\ \text{SUPPORTS}(z, y) \wedge \\ \neg \Diamond \text{SUPPORTED}(x) \wedge \neg \Diamond \text{ATTACHED}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(y, x) \wedge \neg \Diamond \text{SUPPORTS}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(x, z) \wedge \neg \Diamond \text{SUPPORTS}(z, x) \end{array} \right] \end{array} \right) \\
\\
\text{STACK}(w, x, y, z) &\triangleq \left[\begin{array}{l} \neg \Diamond z = w \wedge \neg \Diamond z = x \wedge \neg \Diamond z = y \wedge \\ \text{PUTDOWN}(w, x, y) \wedge \text{SUPPORTS}(z, y) \wedge \neg \text{ATTACHED}(z, y) \end{array} \right] \\
\\
\text{UNSTACK}(w, x, y, z) &\triangleq \left[\begin{array}{l} \neg \Diamond z = w \wedge \neg \Diamond z = x \wedge \neg \Diamond z = y \wedge \\ \text{PICKUP}(w, x, y) \wedge \text{SUPPORTS}(z, y) \wedge \neg \text{ATTACHED}(z, y) \end{array} \right] \\
\\
\text{MOVE}(w, x, y, z) &\triangleq \neg \Diamond y = z \wedge [\text{PICKUP}(w, x, y); \text{PUTDOWN}(w, x, z)] \\
\\
\text{ASSEMBLE}(w, x, y, z) &\triangleq \text{PUTDOWN}(w, y, z) \wedge_{\{<\}} \text{STACK}(w, x, y, z) \\
\\
\text{DISASSEMBLE}(w, x, y, z) &\triangleq \text{UNSTACK}(w, x, y, z) \wedge_{\{<\}} \text{PICKUP}(x, y, z)
\end{aligned}$$

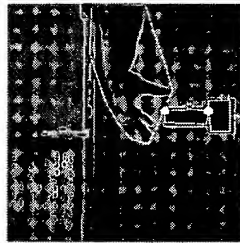
FIG. 4



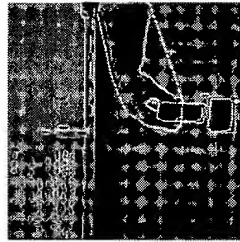
frame 0



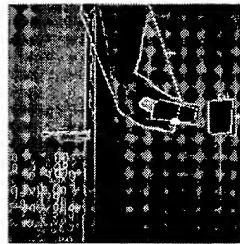
frame 1



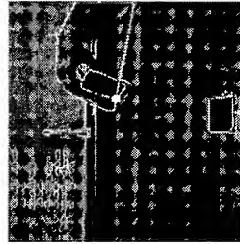
frame 2



frame 13

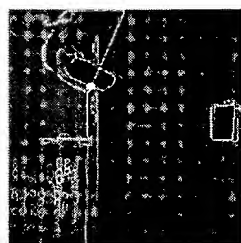


frame 14

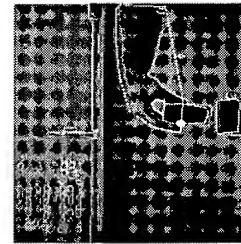


frame 22

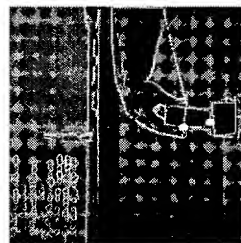
FIG. 5A



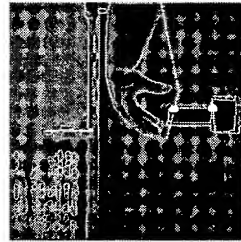
frame 0



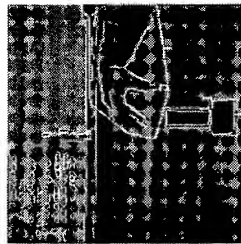
frame 13



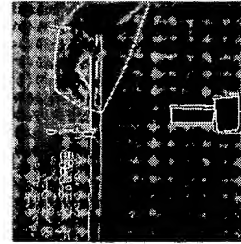
frame 14



frame 22



frame 23



Frame 32

FIG. 5B

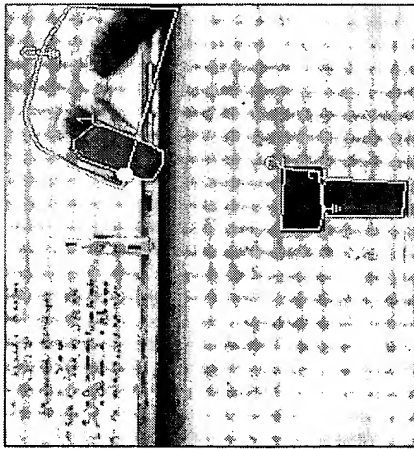
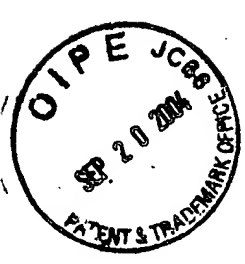


(PICK-UP MOVING RED GREEN)*{([0,1],[14,22])}
(SUPPORTED? RED)*{([0:22])}
(SUPPORTED? MOVING)*{([1:13]), ([24:26])}
(SUPPORTS? RED MOVING)*{([1:13]), ([24:26])}
(SUPPORTS? MOVING RED)*{([13:22])}
(SUPPORTS? GREEN RED)*{([0:14])}
(SUPPORTS? GREEN MOVING)*{([1:13])}
(CONTACTS? RED GREEN)*{([0:2]), ([6:14])}
(ATTACHED? RED MOVING)*{([1:26])}
(ATTACHED? RED GREEN)*{([1:6])}

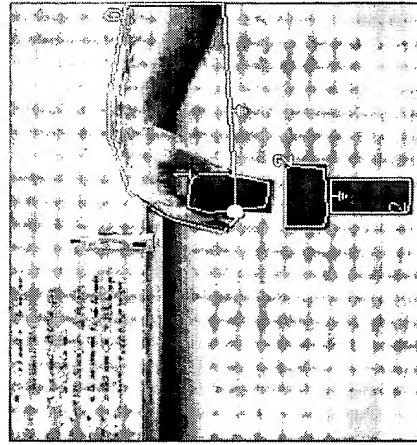
FIG. 6A

(PUT-DOWN MOVING RED GREEN)*{([0,14],[23,32])}
(SUPPORTED? MOVING)*{([14:23])}
(SUPPORTED? RED)*{([0:32])}
(SUPPORTS? MOVING RED)*{([0:14])}
(SUPPORTS? RED MOVING)*{([14:23])}
(SUPPORTS? GREEN MOVING)*{([14:23])}
(SUPPORTS? GREEN RED)*{([14:32])}
(CONTACTS? RED GREEN)*{([22:32])}
(ATTACHED? MOVING RED)*{([0:23])}
(ATTACHED? RED GREEN)*{([14:22])}

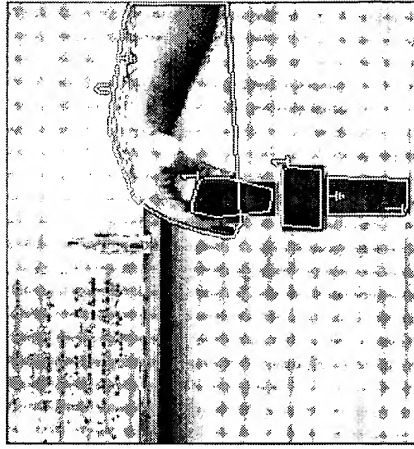
FIG. 6B



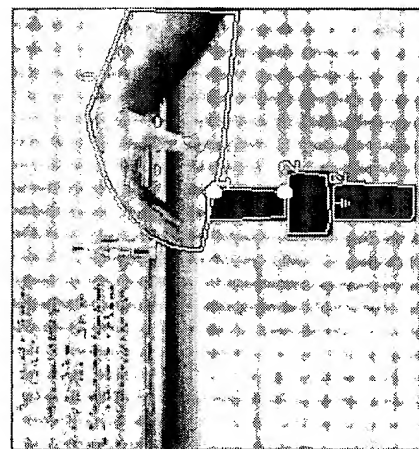
frame 0



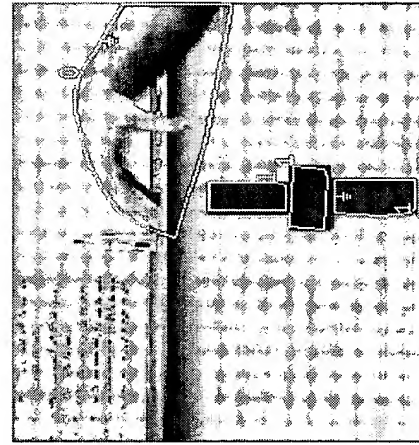
frame 11



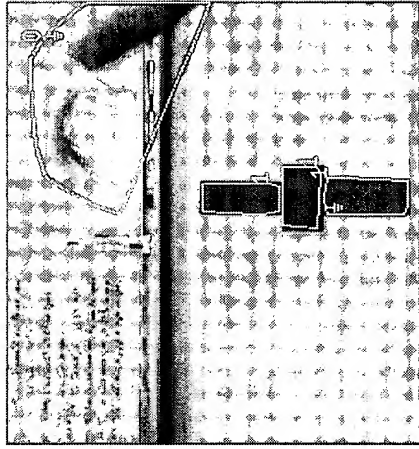
frame 12



frame 23

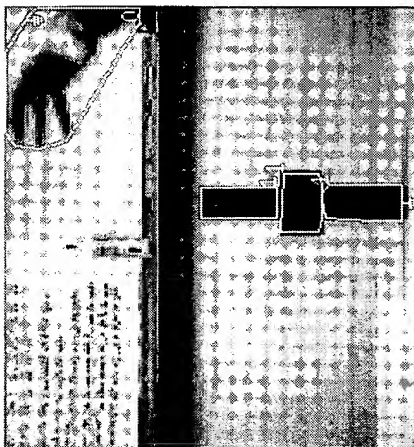


frame 24

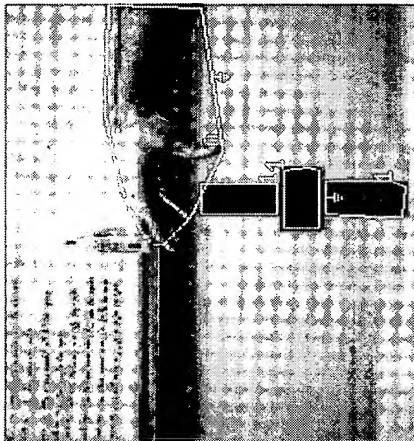


frame 30

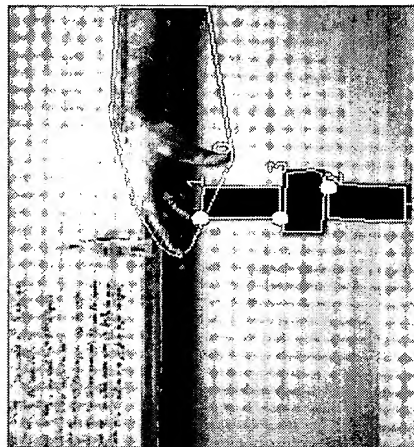
FIG. 7A



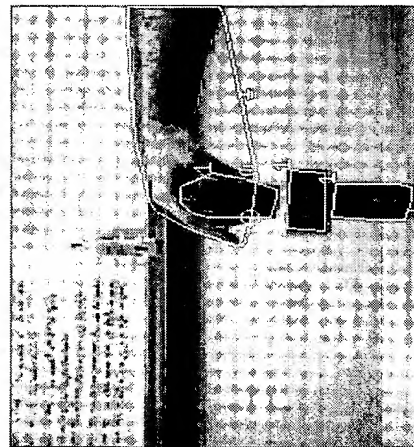
frame 0



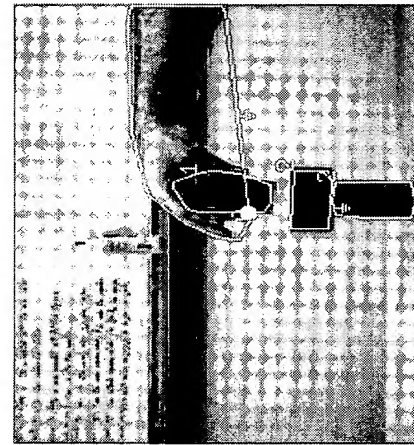
frame 10



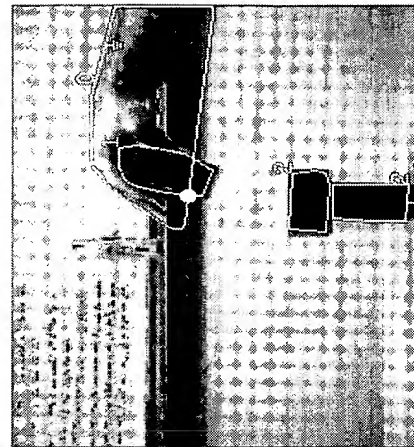
frame 11



frame 24

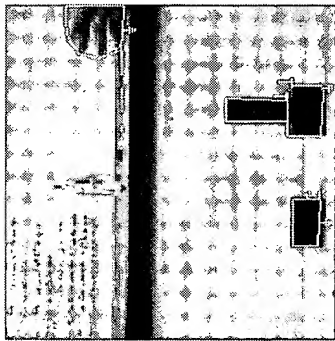
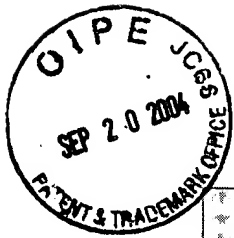


frame 25

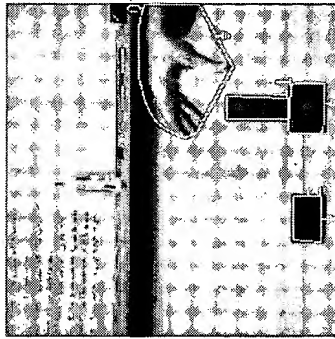


frame 33

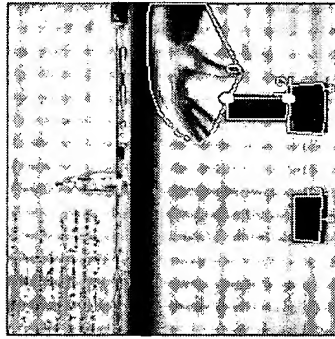
FIG. 7B



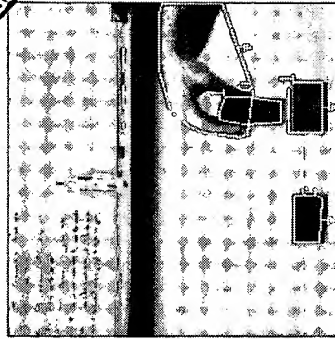
frame 0



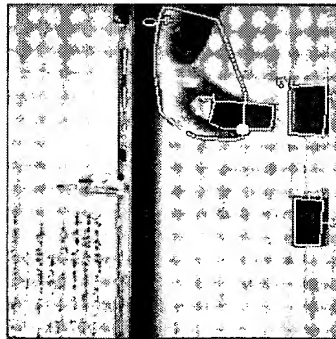
frame 8



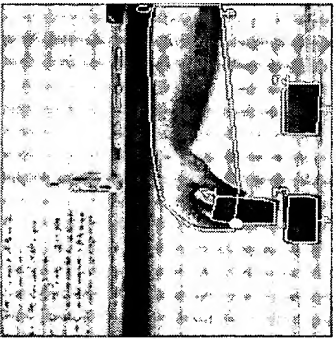
frame 9



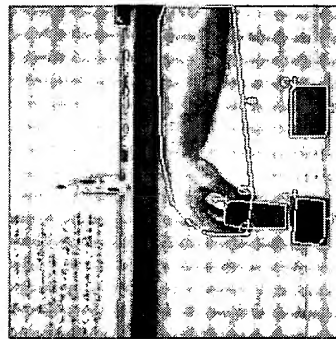
frame 16



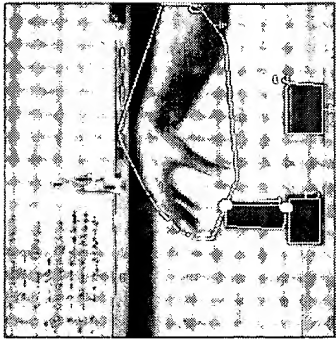
frame 17



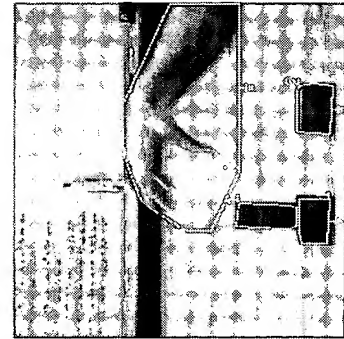
frame 33



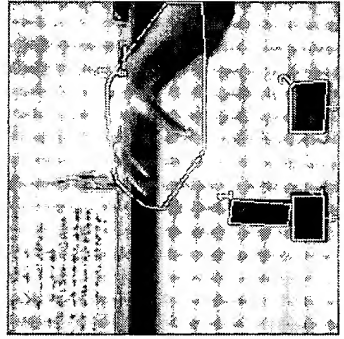
frame 34



frame 45

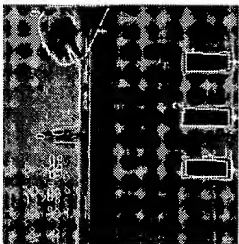


frame 46

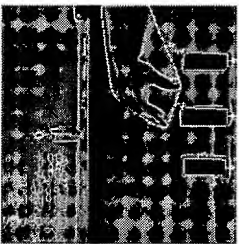


frame 52

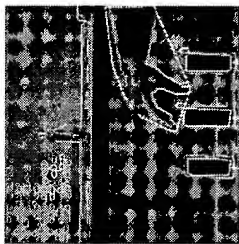
FIG. 7C



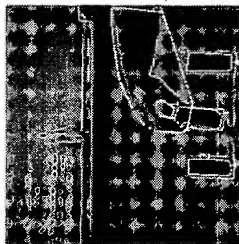
frame 0



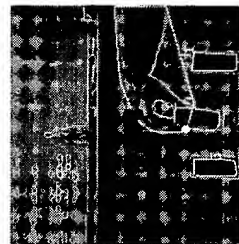
frame 9



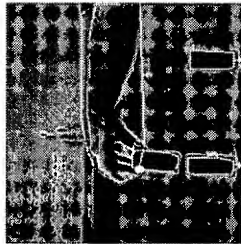
frame 10



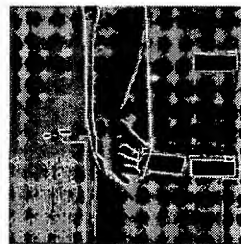
frame 17



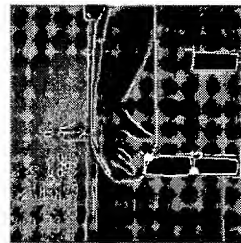
frame 18



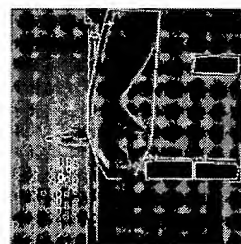
frame 32



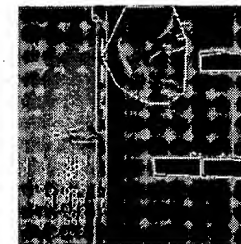
frame 33



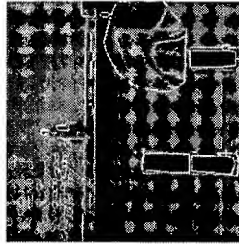
frame 40



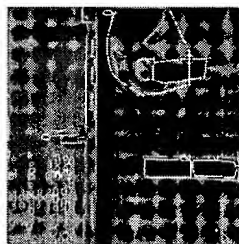
frame 41



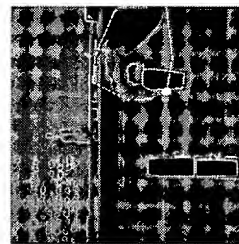
frame 46



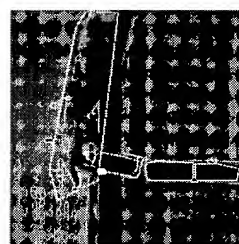
frame 47



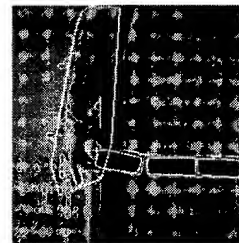
frame 56



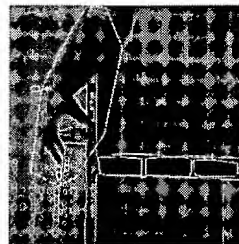
Frame 57



frame 67



frame 68



frame 87

FIG. 7D



```
{PUT-DOWN MOVING RED BLUE}e{[[0,12],[24,30]]}  
{STACK MOVING RED BLUE GREEN}e{[[0,12],[24,30]]}
```

```
{SUPPORTED? MOVING}e{[[13:24]]}  
{SUPPORTED? RED}e{[[0:30]]}  
{SUPPORTED? BLUE}e{[[0:30]]}  
{SUPPORTS? MOVING RED}e{[[0:12]]}  
{SUPPORTS? RED MOVING}e{[[13:24]]}  
{SUPPORTS? RED BLUE}e{[[19:20]], [[21:22]]}  
{SUPPORTS? GREEN MOVING}e{[[19:20]], [[21:22]]}  
{SUPPORTS? GREEN RED}e{[[19:20]], [[21:22]]}  
{SUPPORTS? GREEN BLUE}e{[[0:30]]}  
{SUPPORTS? BLUE MOVING}e{[[13:24]]}  
{SUPPORTS? BLUE RED}e{[[12:30]]}  
{CONTACTS? RED BLUE}e{[[12:19]], [[20:21]], [[22:30]]}  
{CONTACTS? GREEN BLUE}e{[[0:30]]}  
{ATTACHED? MOVING RED}e{[[0:24]]}  
{ATTACHED? RED BLUE}e{[[19:20]], [[21:22]]}
```

FIG. 8A

```
{PICK-UP MOVING RED BLUE}e{[[0,11],[25,33]]}  
{UNSTACK MOVING RED BLUE GREEN}e{[[0,11],[25,33]]}
```

```
{SUPPORTED? MOVING}e{[[11:23]]}  
{SUPPORTED? RED}e{[[0:36]]}  
{SUPPORTED? BLUE}e{[[0:36]]}  
{SUPPORTS? MOVING RED}e{[[23:36]]}  
{SUPPORTS? RED MOVING}e{[[11:23]]}  
{SUPPORTS? RED BLUE}e{[[13:14]]}  
{SUPPORTS? GREEN MOVING}e{[[13:14]]}  
{SUPPORTS? GREEN RED}e{[[13:14]]}  
{SUPPORTS? GREEN BLUE}e{[[0:36]]}  
{SUPPORTS? BLUE MOVING}e{[[11:23]]}  
{SUPPORTS? BLUE RED}e{[[0:25]]}  
{CONTACTS? MOVING RED}e{[[34:36]]}  
{CONTACTS? RED BLUE}e{[[0:13]], [[14:24]]}  
{CONTACTS? GREEN BLUE}e{[[0:13]], [[14:36]]}  
{ATTACHED? MOVING RED}e{[[11:23]]}  
{ATTACHED? RED BLUE}e{[[13:14]]}  
{ATTACHED? GREEN BLUE}e{[[13:14]]}
```

FIG. 8B

```
{PICK-UP MOVING RED GREEN}e{[[0,9],[17,46]]}  
{PUT-DOWN MOVING RED BLUE}e{[[17,35],[46,52]]}  
{MOVE MOVING RED GREEN BLUE}e{[[0,9],[46,52]]}
```

```
{SUPPORTED? MOVING}e{[[9:15]]}  
{SUPPORTED? RED}e{[[0:52]]}  
{SUPPORTED? BLUE}e{[[35:46]]}  
{SUPPORTS? MOVING RED}e{[[17:46]]}  
{SUPPORTS? MOVING BLUE}e{[[35:46]]}  
{SUPPORTS? RED MOVING}e{[[9:15]]}  
{SUPPORTS? RED BLUE}e{[[35:46]]}  
{SUPPORTS? GREEN MOVING}e{[[9:15]]}  
{SUPPORTS? GREEN RED}e{[[0:17]]}  
{SUPPORTS? BLUE RED}e{[[46:52]]}  
{CONTACTS? RED GREEN}e{[[0:17]]}  
{CONTACTS? RED BLUE}e{[[46:52]]}  
{ATTACHED? MOVING RED}e{[[9:46]]}  
{ATTACHED? RED BLUE}e{[[35:46]]}
```

FIG. 8C

```
{PUT-DOWN MOVING RED GREEN}e{[[57,68],[68,87]]}  
{PUT-DOWN MOVING GREEN BLUE}e{[[18,35],[41,47]]}  
{STACK MOVING RED GREEN BLUE}e{[[57,68],[68,87]]}  
{ASSEMBLE MOVING RED GREEN BLUE}e{[[18,35],[68,87]]}
```

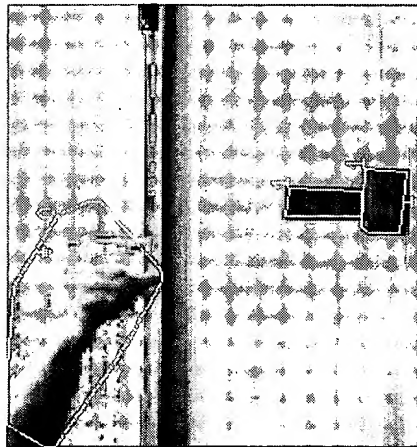
```
{SUPPORTED? MOVING}e{[[10:18]], [[47:57]]}  
{SUPPORTED? RED}e{[[57:87]]}  
{SUPPORTED? GREEN}e{[[11:87]]}  
{SUPPORTED? BLUE}e{[[35:41]]}  
{SUPPORTS? MOVING RED}e{[[57:68]]}  
{SUPPORTS? MOVING GREEN}e{[[11:41]]}  
{SUPPORTS? MOVING BLUE}e{[[35:41]]}  
{SUPPORTS? RED MOVING}e{[[10:18]], [[47:57]]}  
{SUPPORTS? RED GREEN}e{[[11:16]]}  
{SUPPORTS? GREEN RED}e{[[68:87]]}  
{SUPPORTS? GREEN BLUE}e{[[35:41]]}  
{SUPPORTS? BLUE GREEN}e{[[41:87]]}  
{CONTACTS? RED GREEN}e{[[68:87]]}  
{CONTACTS? GREEN BLUE}e{[[41:87]]}  
{ATTACHED? MOVING RED}e{[[11:16]], [[49:68]]}  
{ATTACHED? MOVING GREEN}e{[[11:41]]}  
{ATTACHED? GREEN BLUE}e{[[35:41]]}
```

FIG. 8D

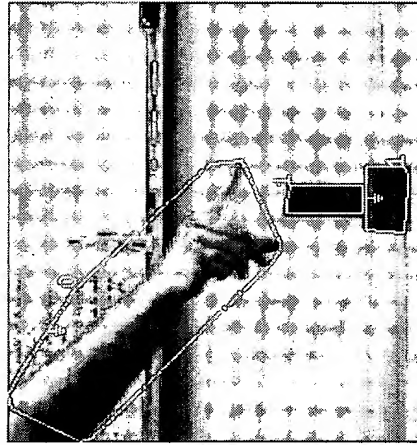
```
{PICK-UP MOVING RED GREEN}e{[[0,19],[23,50]]}  
{PICK-UP MOVING GREEN BLUE}e{[[22,58],[62,87]]}  
{UNSTACK MOVING RED GREEN BLUE}e{[[0,19],[23,50]]}  
{DISASSEMBLE MOVING RED GREEN BLUE}e{[[0,19],[62,87]]}
```

```
{SUPPORTED? MOVING}e{[[19:22]]}  
{SUPPORTED? RED}e{[[0:50]]}  
{SUPPORTED? GREEN}e{[[0:87]]}  
{SUPPORTED? BLUE}e{[[58:62]]}  
{SUPPORTS? MOVING RED}e{[[23:50]]}  
{SUPPORTS? MOVING GREEN}e{[[58:87]]}  
{SUPPORTS? MOVING BLUE}e{[[58:62]]}  
{SUPPORTS? RED MOVING}e{[[19:22]]}  
{SUPPORTS? GREEN MOVING}e{[[19:22]]}  
{SUPPORTS? GREEN RED}e{[[0:23]]}  
{SUPPORTS? GREEN BLUE}e{[[58:62]]}  
{SUPPORTS? BLUE GREEN}e{[[0:58]]}  
{CONTACTS? RED GREEN}e{[[0:23]]}  
{CONTACTS? GREEN BLUE}e{[[0:58]]}  
{ATTACHED? MOVING RED}e{[[19:50]]}  
{ATTACHED? MOVING GREEN}e{[[58:87]]}  
{ATTACHED? GREEN BLUE}e{[[58:62]]}
```

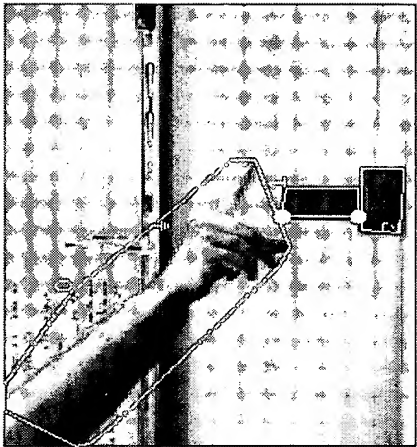
FIG. 8E



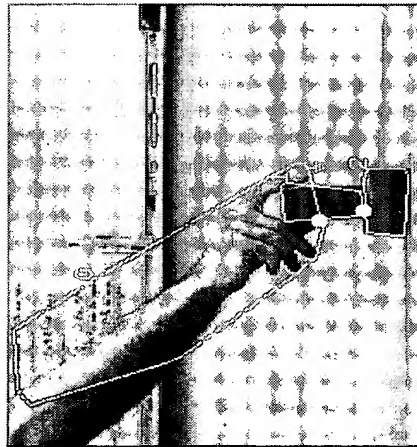
frame 5



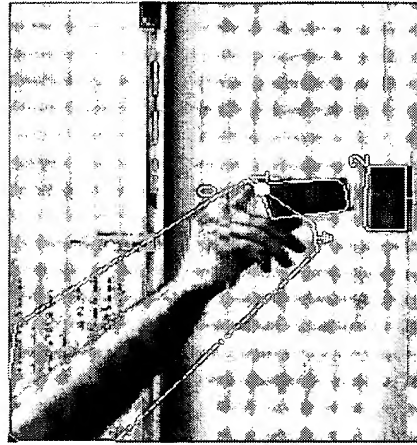
frame 10



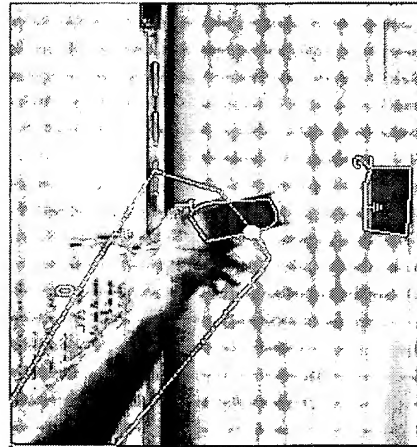
frame 11



frame 17

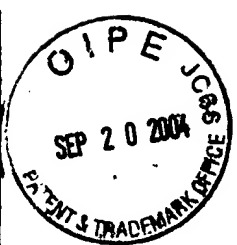


frame 18



frame 22

FIG. 9A



(PICK-UP MOVING RED GREEN)*([[0,11],[18,30]])

(SUPPORTED? RED)*([[0:30]])
(SUPPORTED? GREEN)*([[11:18]])
(SUPPORTS? MOVING RED)*([[11:30]])
(SUPPORTS? MOVING GREEN)*([[11:18]])
(SUPPORTS? RED GREEN)*([[11:18]])
(SUPPORTS? GREEN RED)*([[0:11]])
(CONTACTS? RED GREEN)*([[0:11]])
(ATTACHED? MOVING RED)*([[11:30]])
(ATTACHED? RED GREEN)*([[11:18]])

FIG. 10A

(PICK-UP MOVING RED GREEN)*([[0,8],[19,30]])

(SUPPORTED? MOVING)*([[8:19]])
(SUPPORTED? RED)*([[0:30]])
(SUPPORTED? BLUE)*([[0:30]])
(SUPPORTS? MOVING RED)*([[19:30]])
(SUPPORTS? RED MOVING)*([[8:19]])
(SUPPORTS? GREEN MOVING)*([[8:19]])
(SUPPORTS? GREEN RED)*([[0:19]])
(SUPPORTS? YELLOW BLUE)*([[0:30]])
(CONTACTS? RED GREEN)*([[0:10],[16:19]])
(CONTACTS? BLUE YELLOW)*([[0:30]])
(ATTACHED? MOVING RED)*([[8:30]])
(ATTACHED? RED GREEN)*([[10:16]])

FIG. 10B

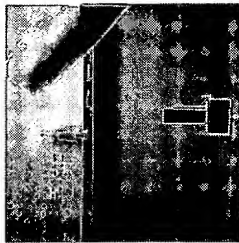
(PICK-UP MOVING RED GREEN)*([[52,70],[78,102]], [[0,9],[19,44]])
(PUT-DOWN MOVING RED GREEN)*([[19,44],[62,70]], [[78,102],[110,117]])
(SUPPORTED? MOVING)*([[9:18],[44:52],[70:77],[102:110]])
(SUPPORTED? RED)*([[0:117]])
(SUPPORTS? MOVING RED)*([[18:44],[78:102]])
(SUPPORTS? RED MOVING)*([[9:18],[44:52],[70:77],[102:110]])
(SUPPORTS? GREEN MOVING)*([[9:18],[44:52],[70:77],[102:110]])
(SUPPORTS? GREEN RED)*([[0:19],[44:78],[102:117]])
(CONTACTS? RED GREEN)*([[0:9],[13:18],[46:70],[106:117]])
(ATTACHED? MOVING RED)*([[9:52],[70:110]])
(ATTACHED? RED GREEN)*([[9:13],[70:76],[104:106]])

FIG. 10C

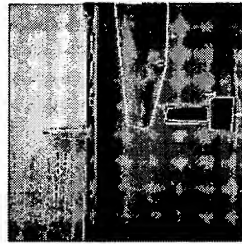
(PICK-UP MOVING RED GREEN)*([[0,6],[16,22]])
(PICK-UP MOVING YELLOW BLUE)*([[0,12],[17,22]])

(SUPPORTED? MOVING)*([[6:16]])
(SUPPORTED? MOVING)*([[12:15]])
(SUPPORTED? RED)*([[0:22]])
(SUPPORTED? YELLOW)*([[0:22]])
(SUPPORTS? MOVING RED)*([[16:22]])
(SUPPORTS? MOVING YELLOW)*([[17:22]])
(SUPPORTS? RED MOVING)*([[6:16]])
(SUPPORTS? GREEN MOVING)*([[6:16]])
(SUPPORTS? GREEN RED)*([[0:16]])
(SUPPORTS? BLUE MOVING)*([[12:15]])
(SUPPORTS? BLUE YELLOW)*([[0:17]])
(SUPPORTS? YELLOW MOVING)*([[12:15]])
(CONTACTS? RED GREEN)*([[0:15]])
(CONTACTS? BLUE YELLOW)*([[0:17]])
(ATTACHED? MOVING RED)*([[6:22]])
(ATTACHED? MOVING YELLOW)*([[12:22]])

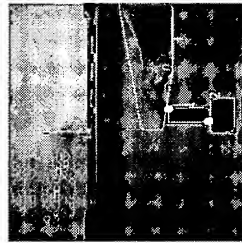
FIG. 10D



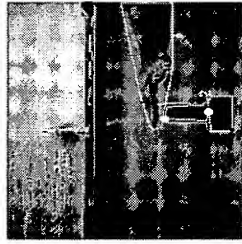
frame 0



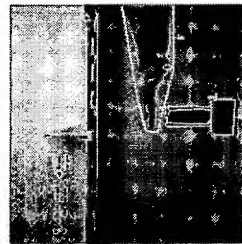
frame 6



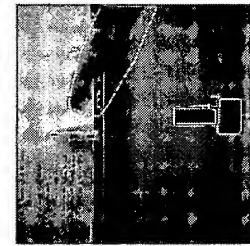
frame 7



frame 12

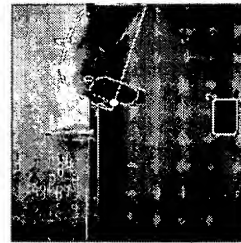


frame 13

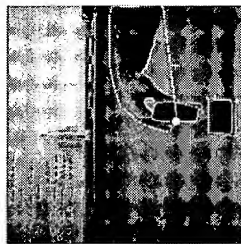


frame 18

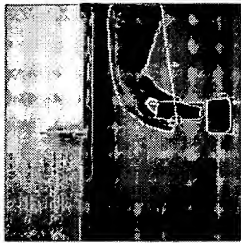
FIG. 11A



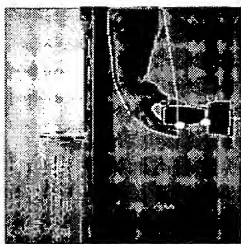
frame 4



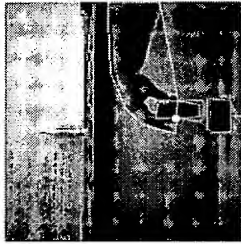
frame 11



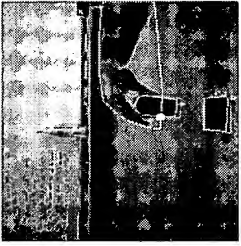
frame 12



frame 18



frame 19



frame 21

FIG. 11B



(SUPPORTED? RED)@([[0:25]])
(SUPPORTED? GREEN)@([[7:13]])
(SUPPORTS? MOVING RED)@([[7:13]])
(SUPPORTS? MOVING GREEN)@([[7:13]])
(SUPPORTS? RED GREEN)@([[7:13]])
(SUPPORTS? GREEN RED)@([[0:7]), [[13:25]])
(CONTACTS? RED GREEN)@([[0:7]), [[13:25]])
(ATTACHED? MOVING RED)@([[7:13]])
(ATTACHED? RED GREEN)@([[7:13]])

FIG. 12A

(SUPPORTED? RED)@([[0:19]])
(SUPPORTED? MOVING)@([[13:31]])
(SUPPORTS? RED MOVING)@([[13:31]])
(SUPPORTS? MOVING RED)@([[0:13]])
(SUPPORTS? GREEN RED)@([[12:19]])
(SUPPORTS? GREEN MOVING)@([[13:19]])
(ATTACHED? RED MOVING)@([[0:31]])
(ATTACHED? RED GREEN)@([[13:19]])

FIG. 12B